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Buck Gully Runoff Water Quality Analysis-Supplemental Report

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Prepared for

Irvine Ranch Water District
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K/J Project No. 0753006

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Section 1: Background

Under Section 303(d) of the Clean Water Act (Act) (Water-Quality-Limited Segments of Receiving Waters), states, territories and authorized tribes are required to develop lists of water-quality-limited segments of receiving waters (also referred to as “impaired waters”). These impaired waters do not meet water quality standards or support designated water uses. The Act requires that priority rankings be established for the impaired waters on the 303(d) lists and Total Maximum Daily Loads (TMDLs) are developed to improve water quality. In California, the Ducheny Bill (AB 1740) requires that the California State Water Resources Control Board (SWRCB) and its nine Regional Water Quality Control Boards develop the 303(d) list(s) and provide an estimated completion date for each TMDL. On February 4, 2003, the SWRCB adopted the 2002 303(d) list of water quality limited segments, and the Buck Gully watershed, located in the Newport Coast area of California, was added to this list. Total coliform and fecal coliform were the pollutants of concern that caused Buck Gully to be added to the list.

The Buck Gully watershed is located in a coastal canyon which drains into an area designated as a State Water Quality Protection Area (formerly Area of Special Biological Significance). The adjacent coastal land is designated as a Critical Coastal Area. The upper portion of the watershed is in the Newport Coast area, and water service is provided by the Irvine Ranch Water District (IRWD). The primary source of the non-point source pollution that enters the Buck Gully is the irrigation runoff from surrounding commercial and large residential developments.

Irrigation runoff flow and nutrient levels (e.g. nitrogen and phosphorous) in Buck Gully fluctuate over time. Over-watering of landscapes and excess application of fertilizers, herbicides, and insecticides are contributors to the elevated loads. Often fertilizers and lawn chemicals are applied to landscapes to improve the appearance and to reduce or eliminate pests and weeds. Unfortunately, when these products are not applied in the correct manner, they migrate if excess water is applied. In addition to landscape chemicals, oil, grease, and other toxic chemicals are also picked up when runoff passes through the streets and discharges into the storm drains. Furthermore, there are environmental factors that contribute to runoff quality, such as animal waste from the wildlife and pets in the area. One potential way to lower the nutrient loading in Buck Gully is by reducing the irrigation runoff.

1.1 Weather-based Irrigation Controllers (Smart Timers)

The Municipal Water District of Orange County (MWDOC) and the Irvine Ranch Water District (IRWD) have previously performed studies (Westpark Study, 1999; Residential Runoff Reduction (R3) Study, 2003) that successfully demonstrated that the installation of weather-based irrigation controllers (Smart Timers) can reduce irrigation water consumption and runoff flow. The weather-based irrigation controller technology automatically adjusts the amount of water applied to the landscape according to current weather conditions. It was the premise of these projects that when the correct amount of water is applied, dry-season runoff is reduced. The data from R3 Study indicated that installation of Smart Timers resulted in 41 gallons-per-day savings (~10% of total household water use) for residential accounts and about 575 gallons-per-day savings for the dedicated landscape irrigation accounts. The reduction in water consumption also resulted in less runoff into the storm drain system. It was observed that a 49% reduction in runoff occurred because of the application of proper water management.

1.2 Buck Gully Runoff Reduction and Water Quality Improvement Study

Following the R3 study, MWDOC was awarded a State Water Resources Control Board Proposition 13 non-point-source pollution control grant for the Residential Runoff and Pollution Reduction Project for the Buck Gully Area. Participants in the Buck Gully Project included the IRWD and MWDOC. The primary responsibilities of MWDOC were organization and administration of the grant agreement. IRWD provided management and implementation of the project, including facilitating the installation of the weather-based irrigation management systems at targeted sites within the study area, and implementing the field monitoring, testing and laboratory analysis of the data.

The premise of this project is that, by utilizing weather-based irrigation scheduling and providing only the amount of irrigation necessary (not over-watering) it is possible to reduce runoff, and correspondingly, reduce the quantity of nutrients running off, to the streets, to the storm drains, and ultimately to the ocean and beaches in the Buck Gully area.

1.3 Report Organization

This report presents an overview of the planning, methodology and results of the Buck Gully Runoff Reduction and Water Quality Improvement Study. Although the Buck Gully study addressed runoff flow reduction and runoff quality evaluation due to the installation of weather-based irrigation controllers, the primary focus of this report is the runoff water quality. Section 1 of the report provides the background of the project. The Study Methodology is described in Section 2. Section 3 provides a brief summary of the runoff flow evaluation. Sections 4 through 6 summarize the results from various concentration-based runoff water quality analyses. Section 7 presents the results from pollutant flux (mass load) analyses. Section 8 summarizes the overall study results.

Section 2: Study Methods

2.1 Buck Gully Watershed and Runoff Monitoring Stations

The Buck Gully Watershed housing developments were constructed over a 10-year period and are comprised of single-family, condominium and multi-family housing, with large common landscaped areas. Most of the irrigation for the landscaped areas is fully and separately metered, under the control of approximately 15 Home Owner Associations (HOAs). The landscaped front yards of most of the housing units are irrigated as part of the common landscaped areas. The backyards of housing units are not separately metered; their irrigation is included as part of the water consumption for the home. Table 1 lists the watershed's characteristics.

Table 1: Buck Gully Watershed Description

Period of Development	1994 to 2003	
Gross Area (approximate)	451 acres	
Irrigated Common Area Landscape	152 acres	
Backyard Irrigated Landscape	10 acres	
Water Meters:		
Condominium	578	55%
Single-Family	308	29%
Multi-Family	66	6%
Landscape Irrigation	72	7%
Homeowner Assoc	11	1%
Retail Development	1	1%
Elementary School	1	1%
Total Meters	1,037	100%

For the Buck Gully Runoff study, IRWD staff surveyed the Buck Gully watershed to determine each monitoring station's location and which areas are tributary to each. Figure 1 shows a schematic overview of the Buck Gully monitoring area, monitoring stations, surrounding basins, and access roads. This evaluation identified two completely isolated watersheds (B1 and B2 in Figure 1). Runoff flow from watershed B1, hereafter referred to as 'Control Area', is monitored using equipment installed at Station #3001, as shown in Figure 1. Runoff flow from watershed B2, hereafter referred to as 'Retrofit Area', is monitored using equipment installed at Station #3011. Monitoring equipment for station 3001 was placed in an underpass, and that for station 3011 was placed at an energy dissipater. Water quality and continuous flow rate monitoring were conducted by IRWD at each station. Water quality grab samples were collected, secured, and transported by the IRWD staff to their certified water quality laboratory, following DHS approved Standard Operating Protocols (SOPs). The continuous flow monitoring equipment (American Sigma 950 Flow Meter) was maintained through site visits on a weekly basis during the monitoring period.

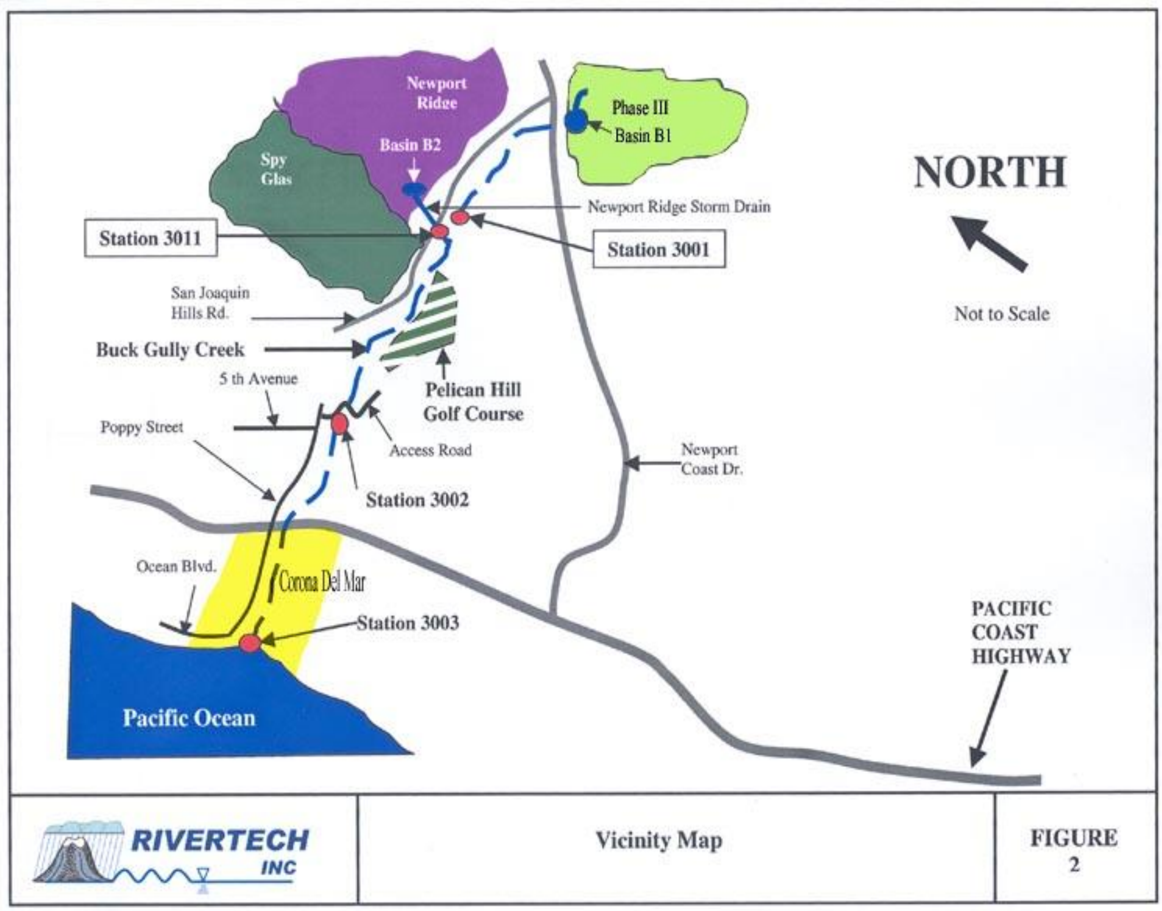

Figure 1: Schematic Map of Buck Gully Study Area

2.2 Smart Timer Installed-Base

For the runoff flow and water quality evaluations in Buck Gully, two areas (Control & Retrofit) with similar characteristics were compared. The Control Area, with no Smart Timers or other known changes, had all runoff flow to Station 3001 for flow monitoring and collection of nutrient data. The Retrofit Area, where Smart Timers were installed, had all runoff flow to Station 3011 for flow monitoring and collection of nutrient data. Each of these stations is separately monitored before flowing into tributaries that eventually flow into Buck Gully.

The common-area landscape in the Retrofit Area is estimated at approximately 85.7 acres. The common-area landscape in the Control Area is estimated at approximately 65.1 acres. These are based on irrigated area submitted to IRWD for the accounts within the identified Retrofit Area. The common area is estimated to represent approximately 75 percent of the total irrigated area within the Retrofit Area. The Retrofit Area had 32 Smart timers installed in year 2005, consisting of five HOAs and one large shopping center. There were 18 other units in the Retrofit Area that were not retrofitted with Smart Timers during the study period. The Control

Area had 37 commercial accounts which were not retrofitted with Smart Timers during the study period.

2.3 Data Set Used

The time-line for the data used for analyses is presented in Table 2 below. The runoff flow and water quality data for the pre-intervention period were collected in 2004. The post-intervention water quality and runoff flow data were collected in 2006. While water quality data collected over a six-month period were used for concentration based analyses, only three-months of data were used for runoff flow and contaminant flux (mass load) analyses. This is due to malfunctions with the flow measurement equipment during initial three months of data collection. Only data collected during non-rainfall days during these months were used for the statistical analyses.

Table 2: Data Set Used for Water Quality Analyses

	Data Collection Period			
Analyses	**Pre-Intervention**	**Post-Intervention**	**Data Collection Frequency**	**Types of Analyses**
Concentration-Based	May – October 2004	May – October 2006	Weekly	Time Series plots, Probability, Box Plots and paired t-test.
Flow	August – October 2004	August – October 2006	Continuous	Paired t-test

2.4 Runoff Flow Data Reduction

Several techniques were used to identify and rectify potential runoff monitoring data quality errors. During the preliminary evaluation it was observed that occasionally the runoff flow was recorded as "0" continuously for several hours or days. Secondly, some of the recorded flow data on dry weather days appeared to be unusually high compared with the typical flow rate measured during the same period on most days. The following data reduction approach was used to address these issues:

- Only dry weather (non-rainfall) day runoff flows were considered for evaluation.
- Rainfall data recorded at IRWD weather stations were used in this study. The recorded data were verified and corrected for accuracy by IRWD staff prior to identifing dry weather days for this study.
- The flow data (1, 5 and 15 minute frequency) were converted to hourly average flow.
- All the "0" hourly data were set aside for correction.
- For the remaining data, the differences in flow rate between consecutive hours were estimated. These differences were then compared with the differences for i) the

previous and next hours of the same day, and ii) the same hours of the previous and next days. Any data where the difference is more than 5 times the base line data used for comparison were selected for further scrutiny. Subsequently, the data were either retained or deleted.

- Next, from the “0” flow data set aside earlier, for those days that had four or fewer hours of recorded “0” flow data, the data was replaced with the hourly average flow of the previous and next day for the same hour.
- Average daily flows were then calculated for each day.
- Finally, for days with more than four hours of “0” flow data, the daily average flow for the month was used as the daily flow data.

2.5 Runoff Flow Data Evaluation Techniques

After the data reduction steps were complete, statistical analyses of the data were performed using paired t-test analyses.

- For comparing the Buck Gully Retrofit and Control area runoff for 2006, the daily average flows were normalized to irrigated acreage in those respective areas.
- Pre and post-retrofit runoff reduction (2004 Area Normalized Runoff – 2006 Area Normalized Runoff) were evaluated for the two stations individually. Paired t-test by matching days was performed for this analysis.
- Evaluations of the relative change in runoff between retrofit and the control stations was performed to selectively identify the impact of Smart Timers on the runoff reduction in the retrofit area. It is assumed in this study that any runoff reduction between 2004 and 2006 in the control area occurred due to various non-Smart Timer factors such as public education, incentives and weather conditions. In the retrofit areas, any observed reduction occurred due to all of the above factors, in addition to the effect of Smart Timers. Hence, the difference in runoff reduction between the retrofit area and control area was assumed as the runoff reduction selectively contributed by the Smart Timers. Table 3 explains this approach.

Table 3: Approach for Runoff Reduction Estimation

Item	Factors Contributing to Runoff Reduction	Estimation Method
Runoff Reduction in Control Area	Include Public Education, Incentives, Weather related issues, etc.	Runoff in 2004 – Runoff in 2006 in control area (1)
Runoff Reduction in Retrofit Area	All of the above + Installation of Smart Timers	Runoff in 2004 – Runoff in 2006 in control area (2)

Item	Factors Contributing to Runoff Reduction	Estimation Method
Runoff reduction in Retrofit Area selectively contributed by installation of smart Timers	Installation of Smart Timers in Retrofit Area	(2) – (1) above

2.6 Runoff Water Quality Data Used

In this study analyses were performed to evaluate concentration and mass flux profiles for the following constituents in the Buck Gully Watershed area:

- Electric Conductivity (EC),
- Nitrate/nitrite (NO_3/NO_2),
- Total Kjeldahl Nitrogen (TKN),
- Ortho Phosphate (Ortho-P) and
- Total Phosphorus (Total-P).

Runoff water quality sample collection periods are shown in Table 2. Approximately sixteen water quality samples each were analyzed during pre- and post-intervention monitoring periods. Only the data on dry weather days were used in these analyses. Trends were compared between pre- and post-intervention period and also, between control (Station 3001) and Retrofit (Station 3011) stations for the common-area landscape irrigation.

2.7 Runoff Quality Data Analyses Methods

The following trend and descriptive statistical analyses were performed for pre- and post-intervention water quality data:

1. Time series plots to visually examine trends
2. Cumulative Frequency and Box Plots to compare pre- and post- intervention trends, as well as control and retrofit area trends
3. Paired t-test to evaluate significant differences in concentration, and
4. Paired t-test to evaluate significant differences in mass flux

Section 3: Runoff Flow Analyses

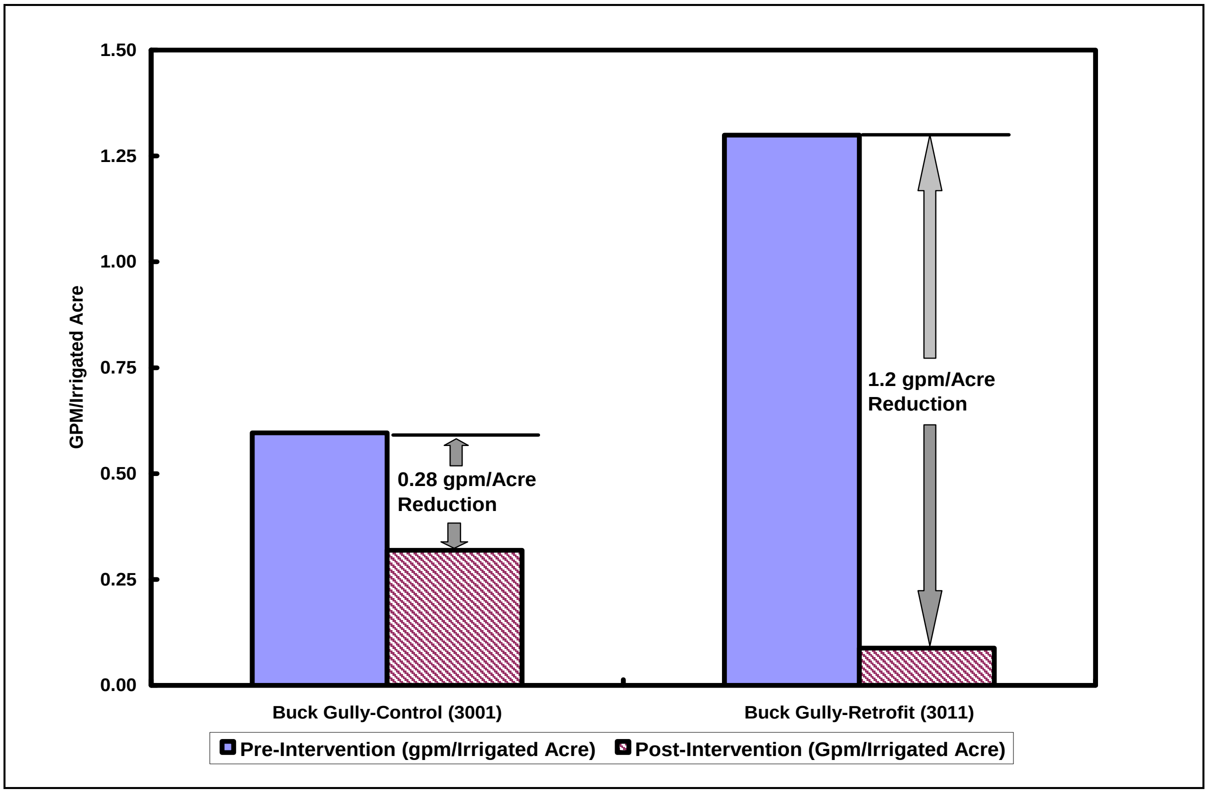

Figure 2: Runoff Flow Rates in Control and Retrofit Areas During Pre- and Post-intervention Period.

Figure 2 shows the summary of paired t-test results for pre- and post-intervention runoff for the Buck Gully Control and Retrofit areas. The runoff flow is normalized to irrigated acres for this analysis. During the pre-intervention period, the weighted runoff in the retrofit area (1.3 gpm/irrigated acre) is significantly higher than that of the Control Area (0.6 gpm/irrigated acre; N = 25, t-stat 7.03, t-critical 2.16). In both areas the runoff flow decreased between 2004 and 2006. In the Control Area alone, the average runoff flow decreased from 0.60 gpm/acre in 2004 to 0.32 gpm/acre (net decrease of about 0.28 gpm/acre). Since there are no known Smart Timers in this area, the decrease in reduction may be attributed to other, non-Smart Timer factors such as consumer education, financial incentives or weather-related irrigation reduction. In the Retrofit Area the runoff flow decreased from 1.3 to 0.1 gpd/acre (net decrease of 1.2 gpm/irrigated acre). The reasons for decrease in runoff in the Retrofit Area may include all the factors associated with the control station in addition to the effect of Smart Timer installations.

Note that the net reduction in runoff for the Retrofit Area was larger than that for the Control Area by about 0.93 gpm/acre. This is a reduction of 2.4 gpm/Smart Timer installed in the retrofit area, during the evaluation period. Since the differences in flow between the two areas were measured under identical conditions, it is reasonable to attribute the reduction observed in this analysis to the installation of Smart Timers.

Section 4: Time Series Analyses

Time series plots for control and retrofit stations were plotted to identify seasonal variation in water quality characteristics. Plots were developed for each of the five constituents considered. Figures 3 to 6 show the time series plots for select constituents. Additional time series plots are shown in Appendix A. In general, the time series plots did not show any apparent differences in water quality during the pre- and post-intervention periods for the Control or Retrofit Areas.

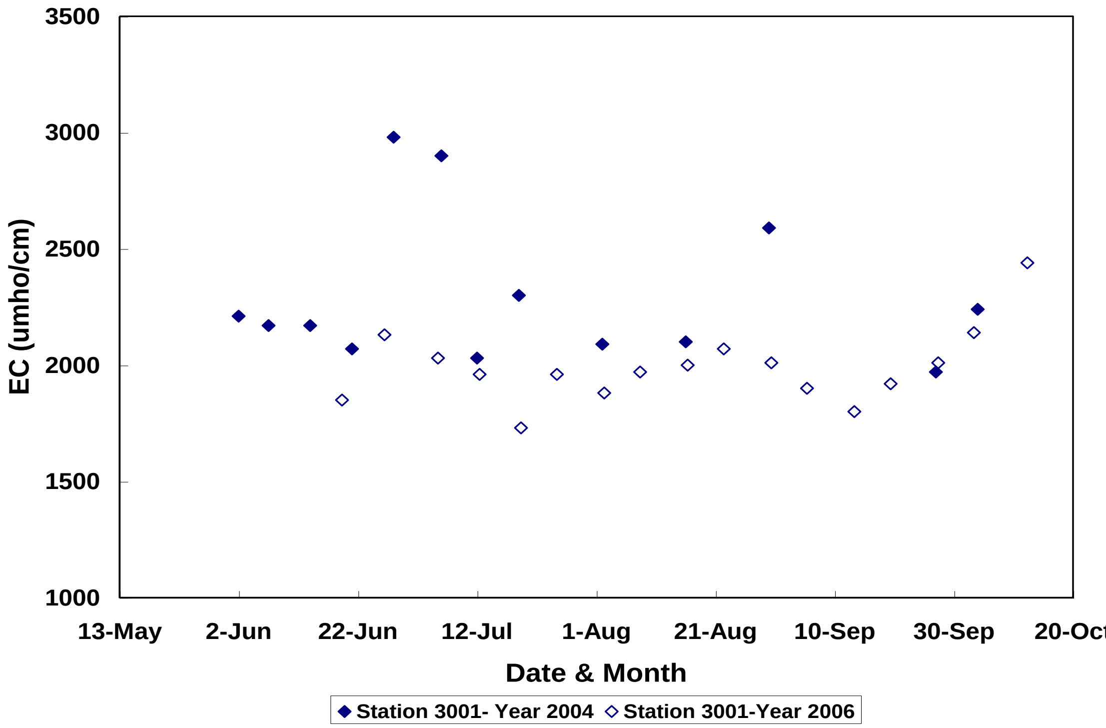

Figure 3: Time Series Plot for Electric Conductivity in Control Area (# 3001) During Pre- and Post-Intervention Periods

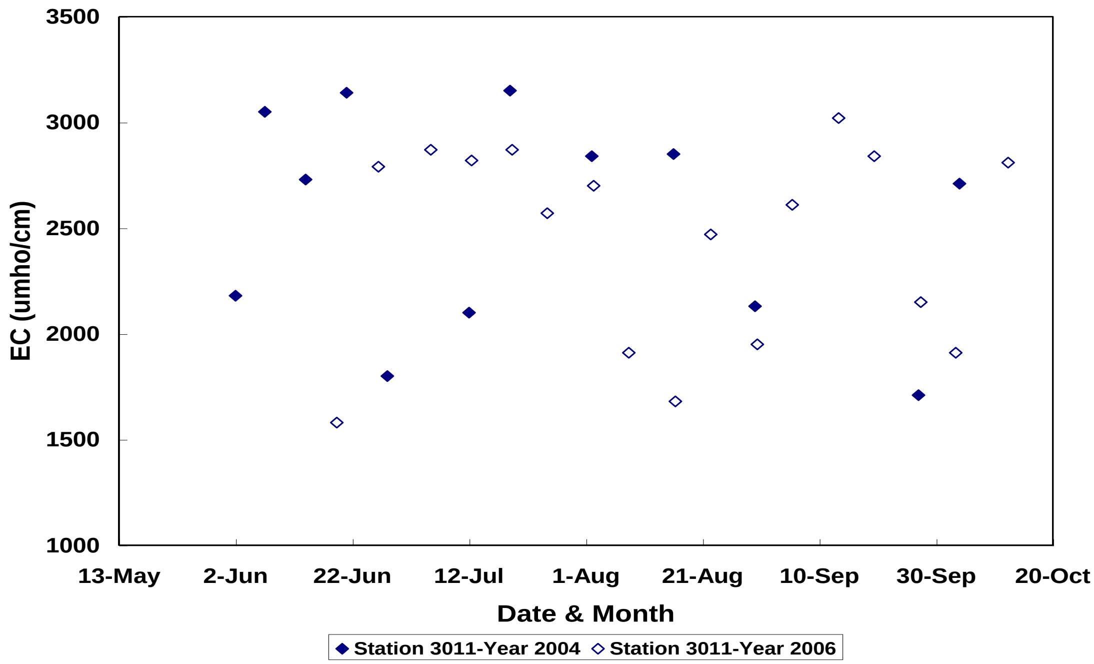

Figure 4: Time Series Plot for Electric Conductivity in Retrofit Area (# 3011) During Pre- and Post-Intervention Periods

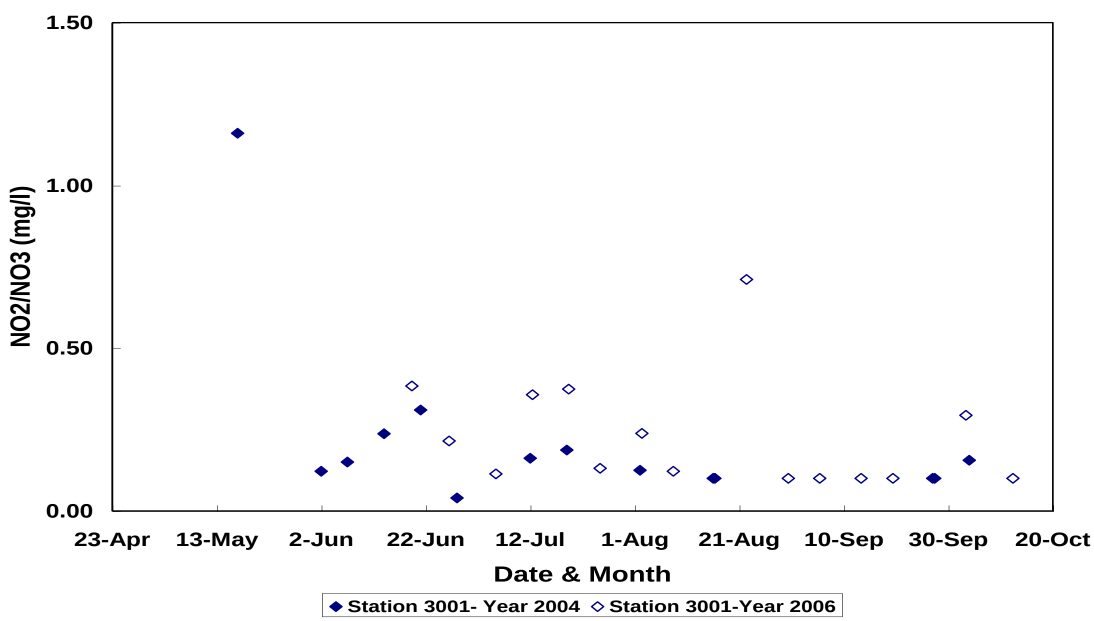

Figure 5: Time Series Plot for Nitrate/Nitrite Levels in Control Area (# 3001) During Pre- and Post-Intervention Periods

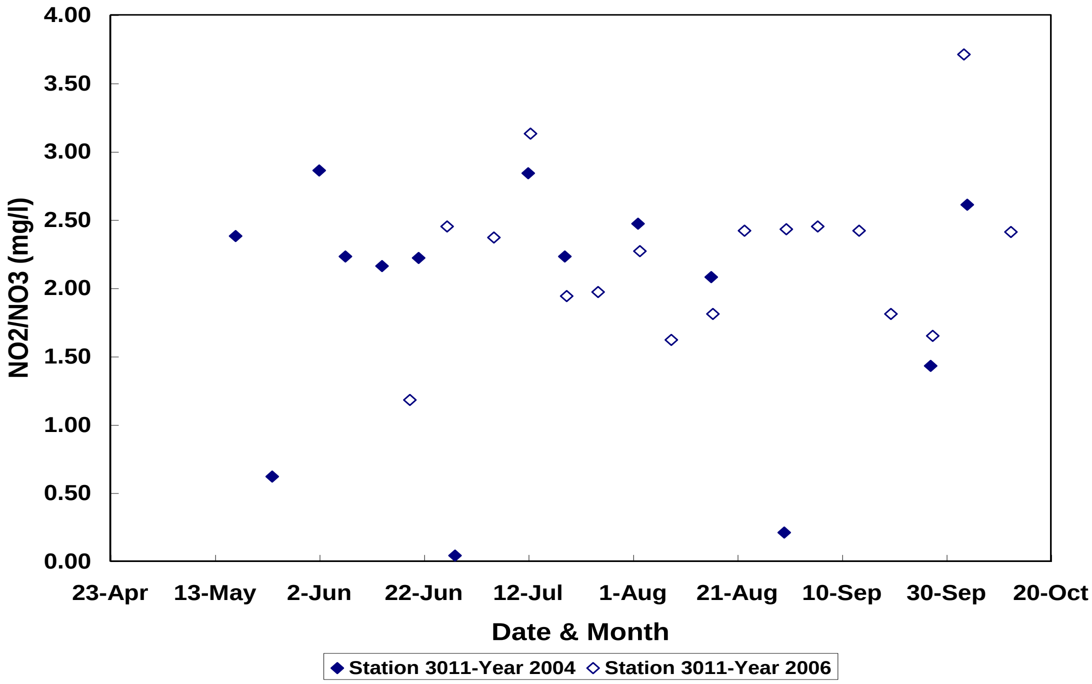

Figure 6: Time Series Plot for Nitrate/nitrite Levels in Retrofit Area (# 3011) During Pre- and Post-Intervention Periods

Section 5: Cumulative Frequency Distribution and Box Plot Analyses

Figures 7 and 8 compare the cumulative frequency distribution of electric conductivity and nitrate/nitrite concentrations for the Control and Retrofit Areas during pre-intervention period. The distribution indicated that the levels of both of these constituents in the retrofit stations were higher than those in control area prior to installation of Smart Timers. The reasons for higher concentrations of EC and nitrate/nitrite are not currently known. The cumulative frequency distributions for other constituents are shown in Appendix B. The distributions for other constituents did not appear to be different between the Control and Retrofit Areas.

Figures 9 and 10 show the cumulative frequency plots for EC and nitrate/nitrate levels. Some interesting trends were observed during these analyses. The frequency plots indicated that the EC levels in the Control Area decreased during the post-intervention period (Figure 9). Furthermore, the variability in concentration also decreased during the post-intervention period for the Control Area. However, in the Retrofit Area, the cumulative distribution trend did not vary noticeably between the pre- and post-intervention periods. The EC levels in the Retrofit Area remained higher than the Control Area during most of the project period. As discussed in the previous section, the NO3/NO2 levels in the Retrofit Area prior to the installation of Smart Timers were noticeably higher than that of the Control Area. The NO3/NO2 levels (Figure 10) did not vary substantially during the post-retrofit period for the Control or Retrofit Areas. The post-intervention nitrate/nitrite levels in the Retrofit Area remained higher than that of the Control Area. However, the data variability appeared to be less during the post-intervention period. No appreciable differences in the cumulative distribution were observed for TKN, Ortho-P or Total-P between the pre-and post-intervention periods (Appendix B).

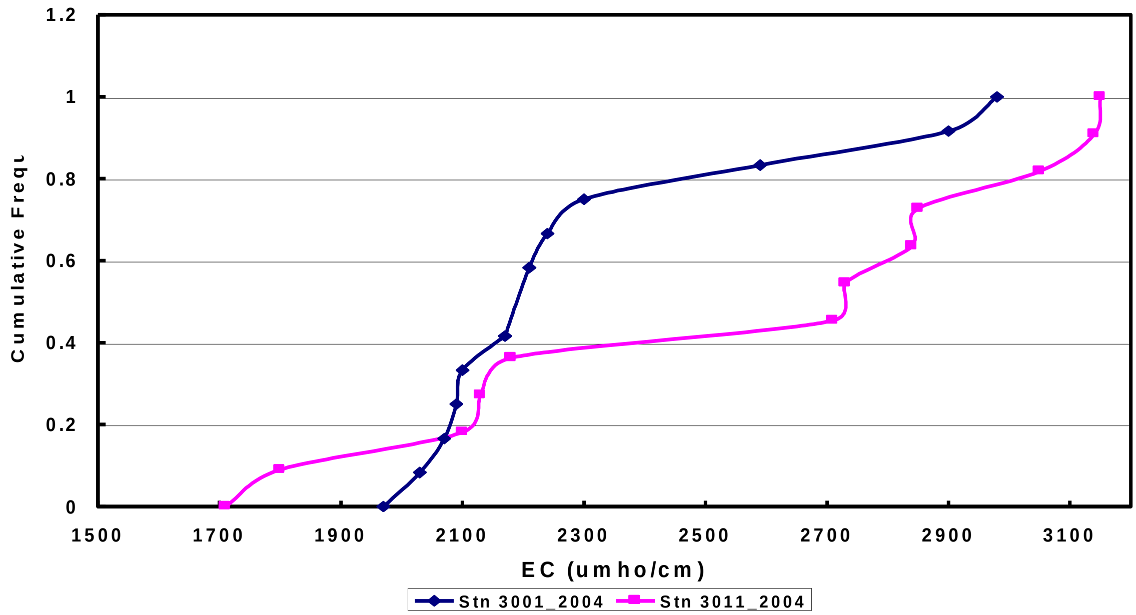

Figure 7: Cumulative Frequency Plot for EC Levels in Control and Retrofit Areas Prior to Installation of Smart Timers

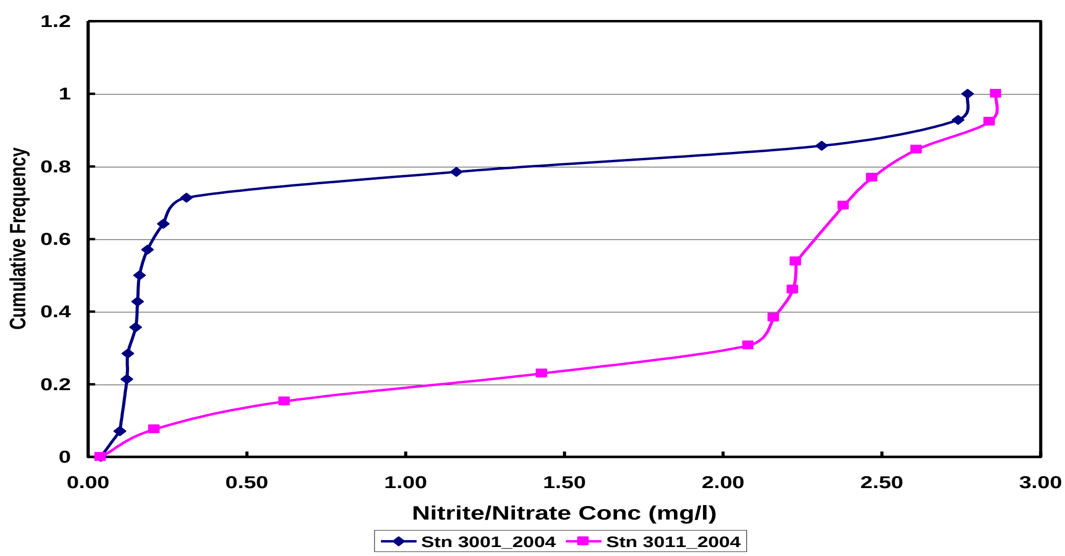

Figure 8: Cumulative Frequency Plot for NO_3/NO_2 Levels in Control and Retrofit Areas Prior to Installation of Smart Timers

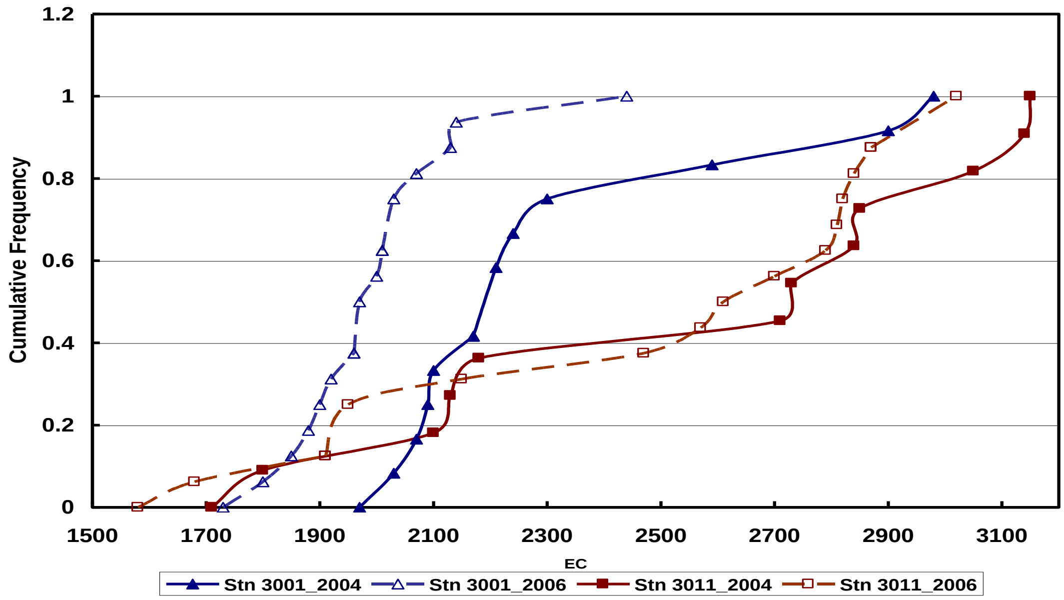

Figure 9: Cumulative frequency Plot for EC Levels in Control and Retrofit Areas Prior to and After Installation of Smart Timers

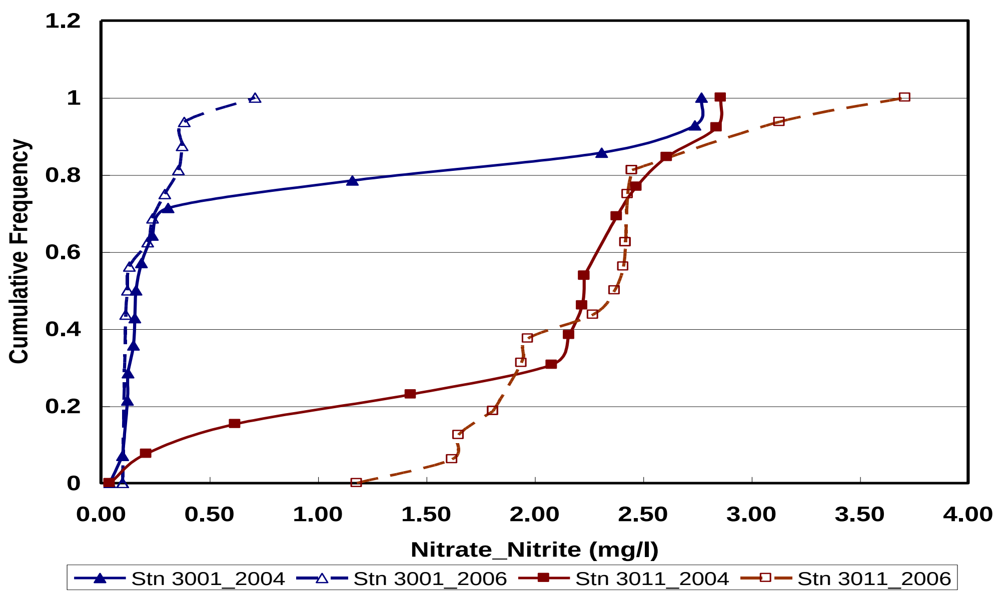

Figure 10: Cumulative frequency Plot for NO3/NO2 Levels in Control and Retrofit Areas Prior to and After Installation of Smart Timers

Tables 4 and 5 show descriptive statistics for various water quality parameters for the Control and Retrofit Areas. During the pre-intervention period the measure of central tendencies (mean, median) and variability (standard deviation) for EC and NO3/NO2 concentrations for the Control Areas were substantially different from that of the Retrofit Area. This suggested that the data arose from different distributions. The trends for other water quality parameters (TKN, Ortho-P, Total-P), however, did not vary appreciably between the Control and Retrofit Areas. Only in one case (control station NO3/NO2) did the mean value differ substantially from the median value. This suggested that outlier data played only a minor role in the data distribution trends observed.

Table 4: Descriptive Statistics for Control Area (# 3001) Before and After Smart Timer Installation

Statistics	EC		NO_3/NO_2		TKN		Ortho-P		Total - P	
	Yr 2004	Yr 2006	Yr 2004	Yr 2006	Yr 2004	Yr 2006	Yr 2004	Yr 2006	Yr 2004	Yr 2006
N	13	17	15	17	14	17	15	17	15	17
Mean	2294	1988	0.71	0.21	0.70	0.51	0.39	0.46	0.42	0.44
Median	2170	1970	0.16	0.12	0.68	0.42	0.32	0.43	0.32	0.34
Max	29980	2440	2.77	0.71	1.1	1.6	1.29	1.1	1.25	1.15
Min	1970	1730	0.04	0.1	0.3	0.3	0.04	0.075	0.1	0.2
Std. Dev	325	159	1.02	0.17	0.26	0.32	0.32	0.22	0.34	0.24
25^{th} Percentile	2090	1900	0.12	0.1	0.58	0.32	0.19	0.36	0.19	0.28
75^{th} Percentile	2300	2030	1.16	0.29	0.86	0.55	0.42	0.49	0.43	0.58
IQR*	310	130	1.04	0.19	0.29	0.24	0.23	0.13	0.23	0.3

IQR – Inter Quartile Range

Table 5: Descriptive Statistics for Retrofit Area (# 3011) Before and After Smart Timer Installation

Statistics	EC		NO_3/NO_2		TKN		Ortho-P		Total - P	
	Yr 2004	Yr 2006	Yr 2004	Yr 2006	Yr 2004	Yr 2006	Yr 2004	Yr 2006	Yr 2004	Yr 2006
N	12	17	14	17	14	17	14	17	14	17
Mean	2533	2444	1.88	2.24	0.72	1.01	0.39	0.49	0.42	0.51
Median	2720	2610	2.2	2.4	0.72	0.84	0.32	0.35	0.37	0.44
Max	3150	3020	2.86	3.71	1.32	2.49	1.24	1.24	1.31	1.21
Min	1710	1580	0.04	1.18	0.3	0.3	0.12	0.19	0.1	0.2
Std. Dev	520	473	0.94	0.59	0.29	0.69	0.3	0.3	0.31	0.29
25^{th} Percentile	2122	1950	1.59	1.84	0.47	0.51	0.19	0.3	0.22	0.29
75^{th} Percentile	2900	2820	2.4	2.4	0.83	1.45	0.5	0.46	0.53	0.63
IQR	777	880	0.86	0.6	0.36	0.95	0.32	0.16	0.31	0.34

IQR – Inter Quartile Range

Similar comparisons during the post-intervention period indicated that the data distributions were different between the two areas for all of the water quality parameters evaluated. In general, the mean and median values for the Retrofit Area appeared higher than those for the Control Area. Finally, outliers appeared to play only a minor role in the post-intervention data.

Comparison of central tendencies between the pre- and post-intervention data for the Control Area indicated substantial differences for all of the water quality parameters except total-P. This indicated that these data belonged to different distributions. Furthermore, for EC, NO_3/NO_2 and TKN, the mean and median values decreased during the post-intervention period. The mean and median values for ortho-P and total-P slightly increased during the post-intervention period.

The trends in pre- and post-intervention data for the Retrofit Area differed from those observed for the Control Area. The EC values slightly decreased and the other parameter levels slightly increased during the post-intervention period. Furthermore, the standard deviation for the pre- and post-intervention periods did not change substantially.

Figures 11 and 12 show the box plot for EC and nitrate/nitrite trends for the Control and Retrofit Areas. The box plot trends were generally consistent with the cumulative frequency plots and descriptive statistics table. For the Control Area, the mean EC values were lower than those for the Retrofit Area. Furthermore, the data variability (IQR) for the Control Area was lower than those for the Retrofit Area. Similarly, the nitrate/nitrite concentrations for the Control Area were lower than the Retrofit Area values before and after the installation of Smart Controllers in the Retrofit Area. The box plots for the remaining parameters are in Appendix B. Unlike the EC and NO_3/NO_2 trends, the box plots for TKN, ortho-P and total-P for the Retrofit Area were not substantially different than those of Control Area. The data variability (IQR) for the Retrofit Area appeared to be high in some cases than those for the Control Area.

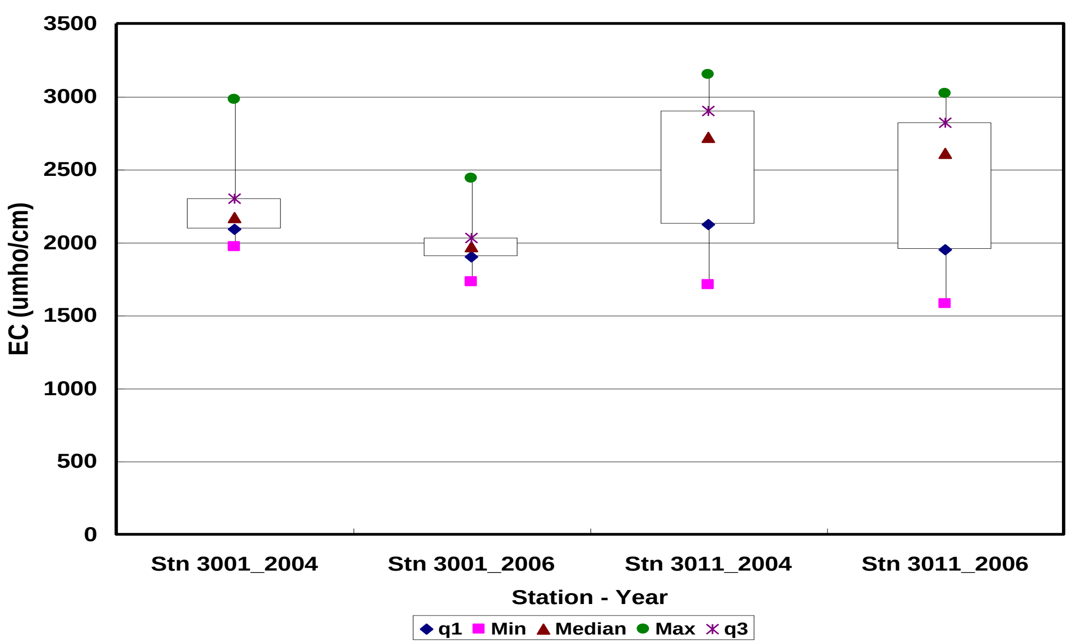

Figure 11: Box Plot for EC Levels in Control and Retrofit Areas Prior to Installation of Smart Timers

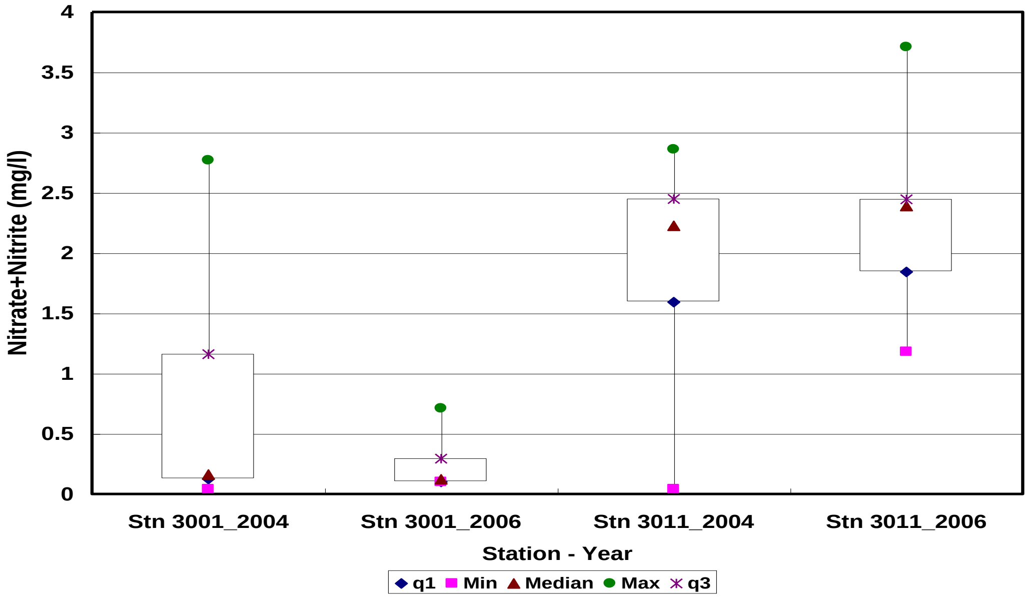

Figure 12: Box Plot for Nitrate/nitrite Levels in Control and Retrofit Areas Prior to Installation of Smart Timers

Section 6: Paired T-test for Comparing Concentrations of Water Quality Parameters

Paired t-tests were performed if significant differences existed in concentrations of water quality parameters under various scenarios. Figures 13 through 16 show the results from the analyses. The solid bars in these figures indicate that the differences are not statistically significant (α = 0.05). The hatched bars indicate statistically significant differences. As shown in Figure 13, the nitrate/nitrite concentrations in the Retrofit Area were significantly higher than those of the Control Area prior to the installation of Smart Timers. After installation of the Smart Timers, EC, nitrate/nitrite as well as TKN values for the Retrofit Area were higher than those of the Control Area (Figure 14).

For the Control Area, a significant decrease in EC levels and an increase in Ortho-P levels occurred in the post-intervention monitoring period (Figure 15). For the Retrofit Area none of the water quality parameters concentrations changed significantly after installation of the Smart Timers (Figure 16).

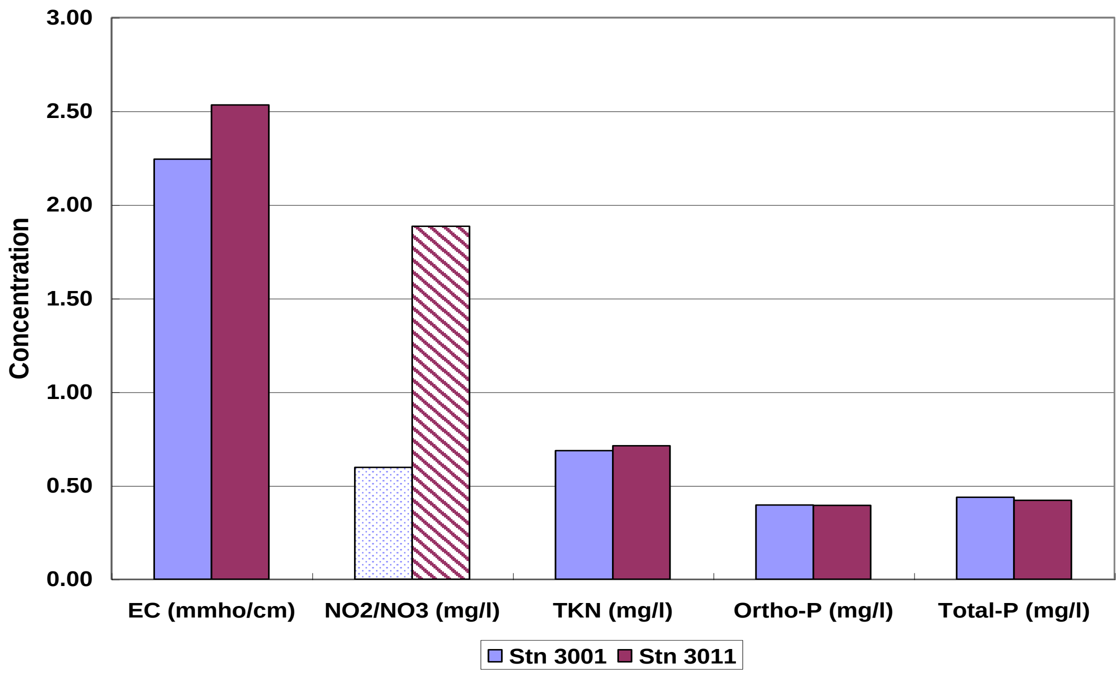

Figure 13: Mean Concentration of Various Water Quality Parameters for Control (# 3001) and Retrofit Areas (# 3011) During Pre-Intervention Period. (The dotted/stashed bars mean the concentrations are statistically different)

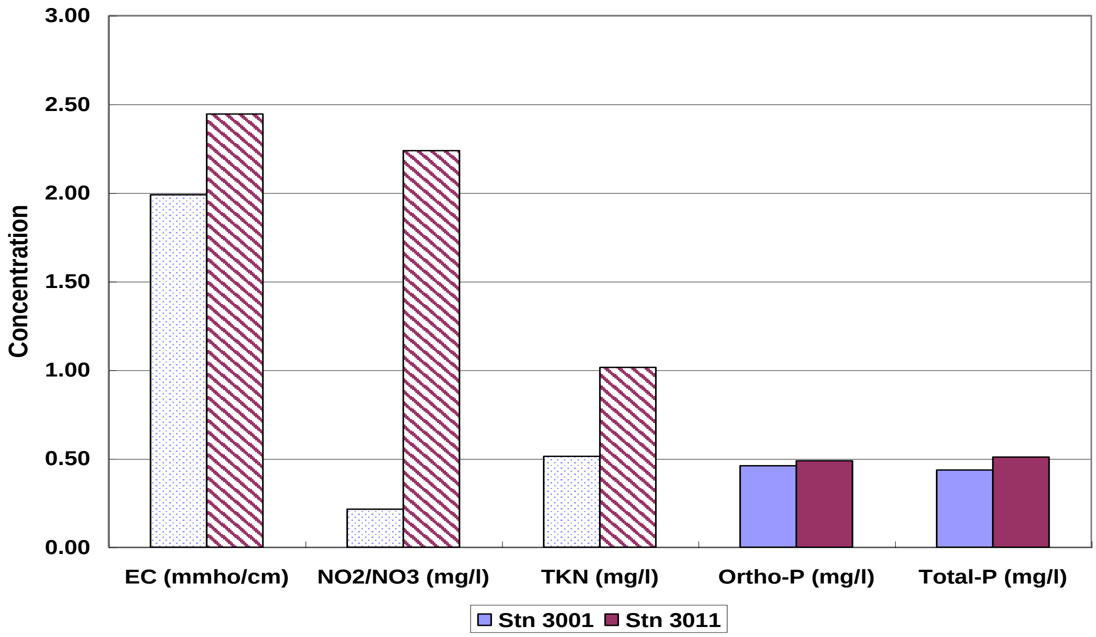

Figure 14: Mean Concentration of Various Water Quality Parameters for Control (# 3001) and Retrofit Areas (# 3011) During Post-Intervention Period. (The dotted/stashed bars mean the concentrations are statistically different)

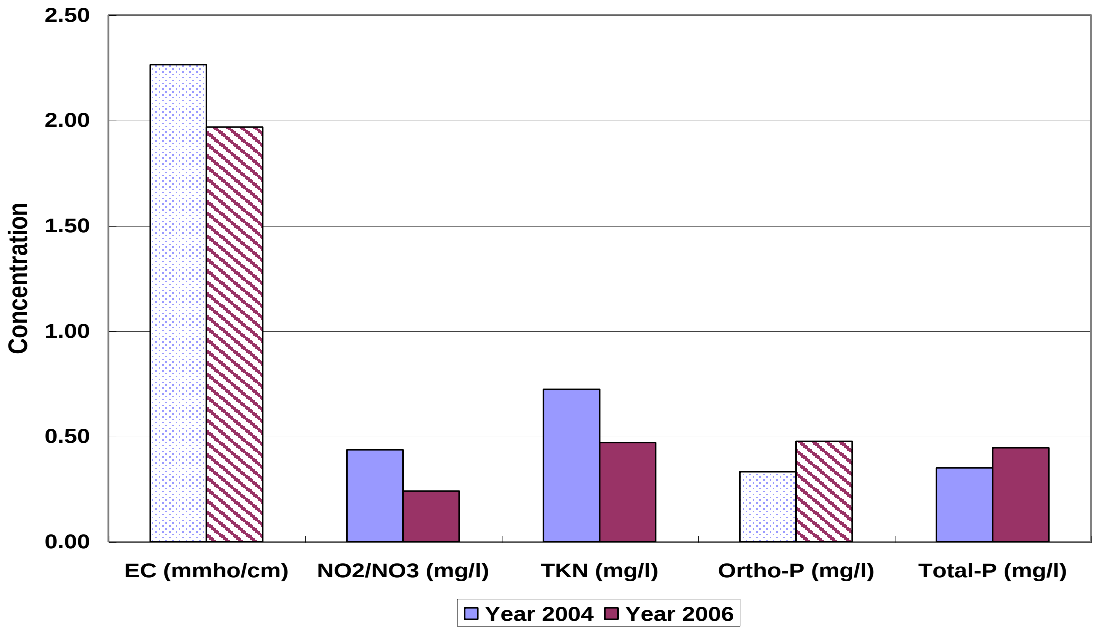

Figure 15: Mean Concentration of Various Water Quality Parameters for Control Area (# 3001) During Pre- and Post-Intervention Period. (The dotted/stashed bars mean the concentrations are statistically different)

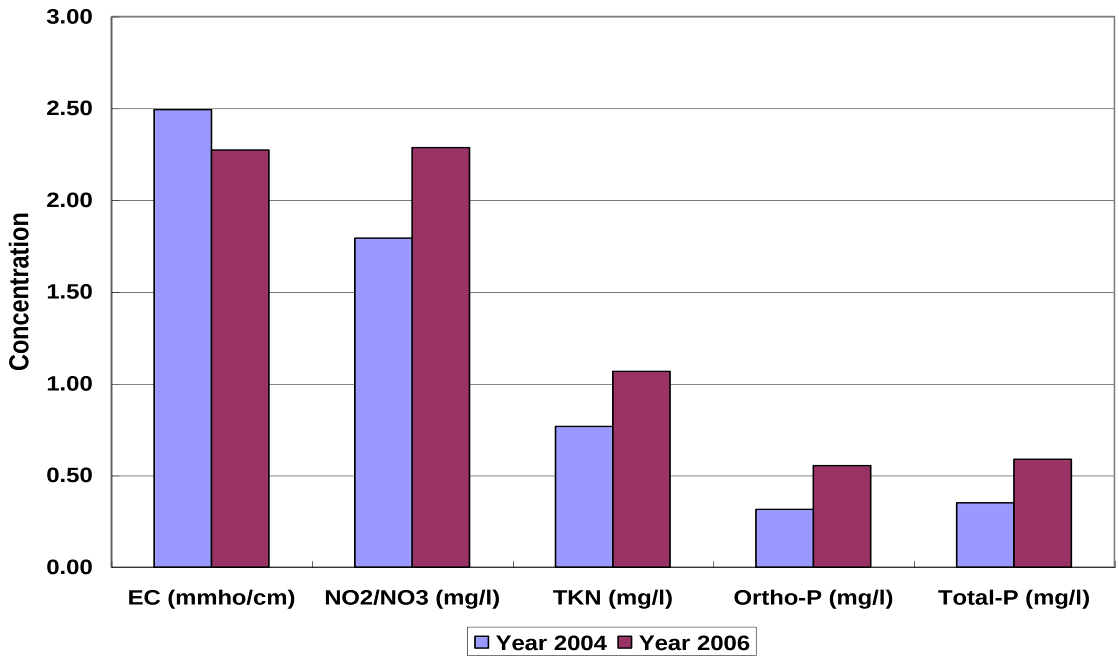

Figure 16: Mean Concentration of Various Water Quality Parameters For Retrofit Area (# 3001) During Pre- and Post-Intervention Period. (The dotted/stashed bars mean the concentrations are statistically different)

Section 7: Paired T-test for Total Pollutant Flux

Paired t-tests were also performed to evaluate the mass flux rate for the water quality parameters. The mass flux for the Control and Retrofit Areas were normalized to irrigated area (Mass Flux = [flow X concentration] / Irrigated Area) for comparison. As discussed in Section 3, the runoff flow in the Control Area decreased from 0.6 gpm/irrigated acre in the pre-intervention period (2004) to 0.32 gpm/irrigated acre in the post-intervention period (2006). In the Retrofit Area, the runoff flow decreased from 1.3 to 0.1 gpm/irrigated acre during the same time. The average flow rates on the date of the water quality sample collections were used for the estimation of mass flux values.

Paired t-test results for mass flux are shown in Figures 17 through 19. For the Control Station, the mass flux for EC and TKN decreased significantly during the post-intervention period (Figure 17). The flux for other parameters were not statistically different during pre- and post-installation period. For the retrofit station, EC, nitrate/nitrite and TKN flux decreased significantly after the installation of Smart Timers (Figure 18). Note that the concentrations of these parameters in the runoff did not decrease significantly after installation of the Smart Timers. Hence, the reduction in flux occurred predominantly due to the reduction in runoff flow.

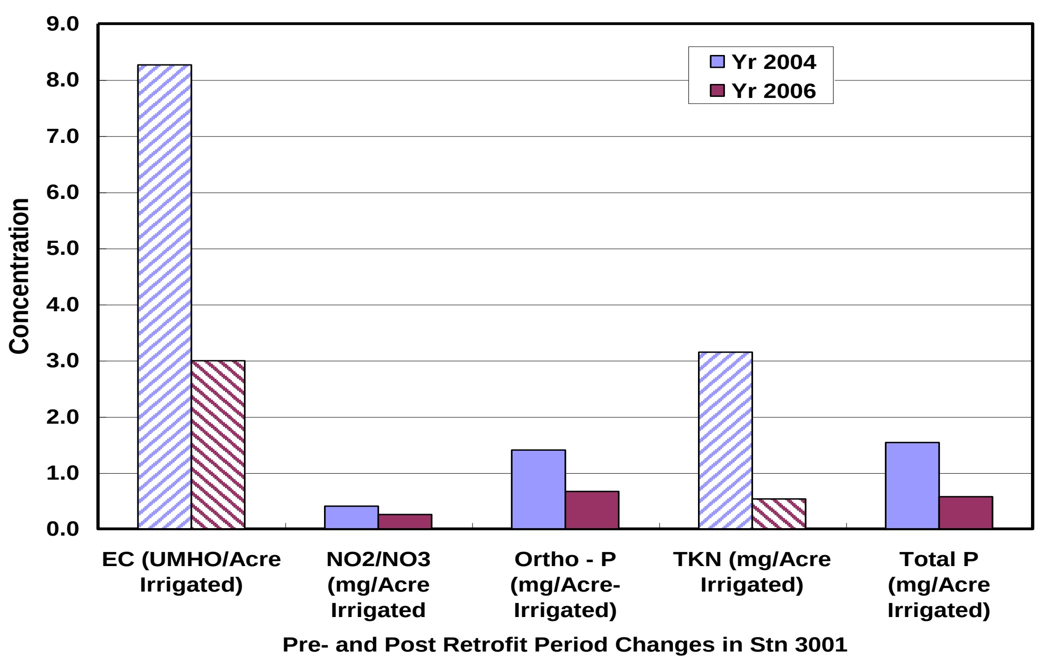

Figure 17: Mean Mass Flux of Various Water Quality Parameters for Control Area (# 3001) During Pre- and Post-Intervention Period. (The dotted/stashed bars mean the mass flux are statistically different)

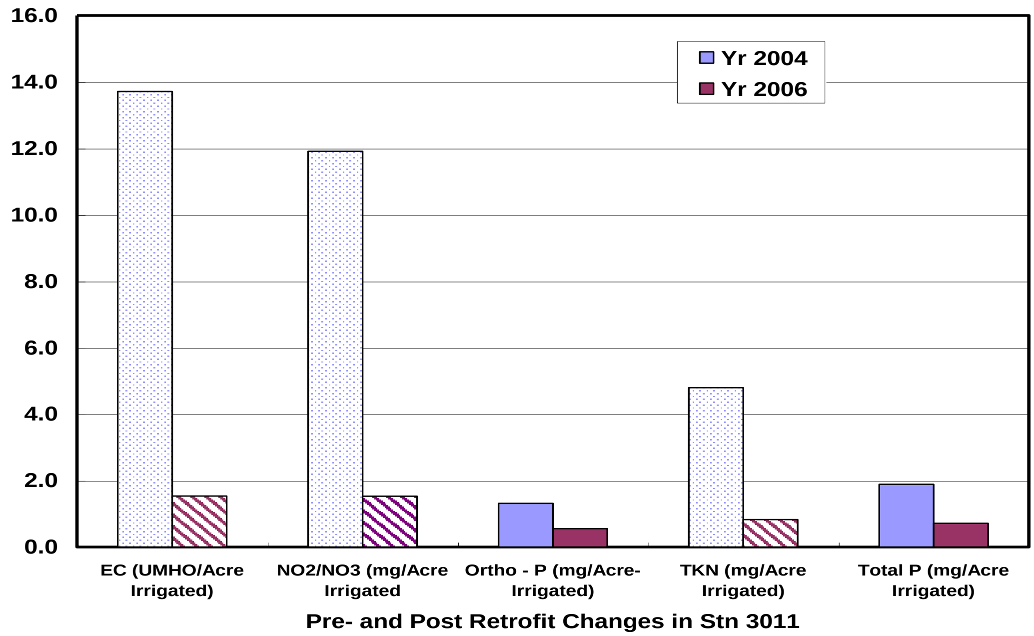

Figure 18: Mean Mass Flux of Various Water Quality Parameters for Retrofit Area (# 3011) During Pre- and Post-Intervention Period. (The dotted/stashed bars mean the concentrations are statistically different)

Finally, paired t-tests were performed to compare the change (= mass flux in 2004 – mass flux in 2006) in mass flux in the Control Area with that in the Retrofit Area. Figure 19 shows the results from these analyses. Note that a larger bar in this figure indicates a <u>greater</u> reduction in mass flux. T-test data indicated that, reductions in EC and nitrate/nitrite flux in the Retrofit Area were significantly greater than those in the Control Station. Since, the concentration of these parameters did not significantly decrease, the reduction in the mass flux for the Retrofit Area can be attributed to the reduction in runoff flow rate due to the installation of Smart Timers.

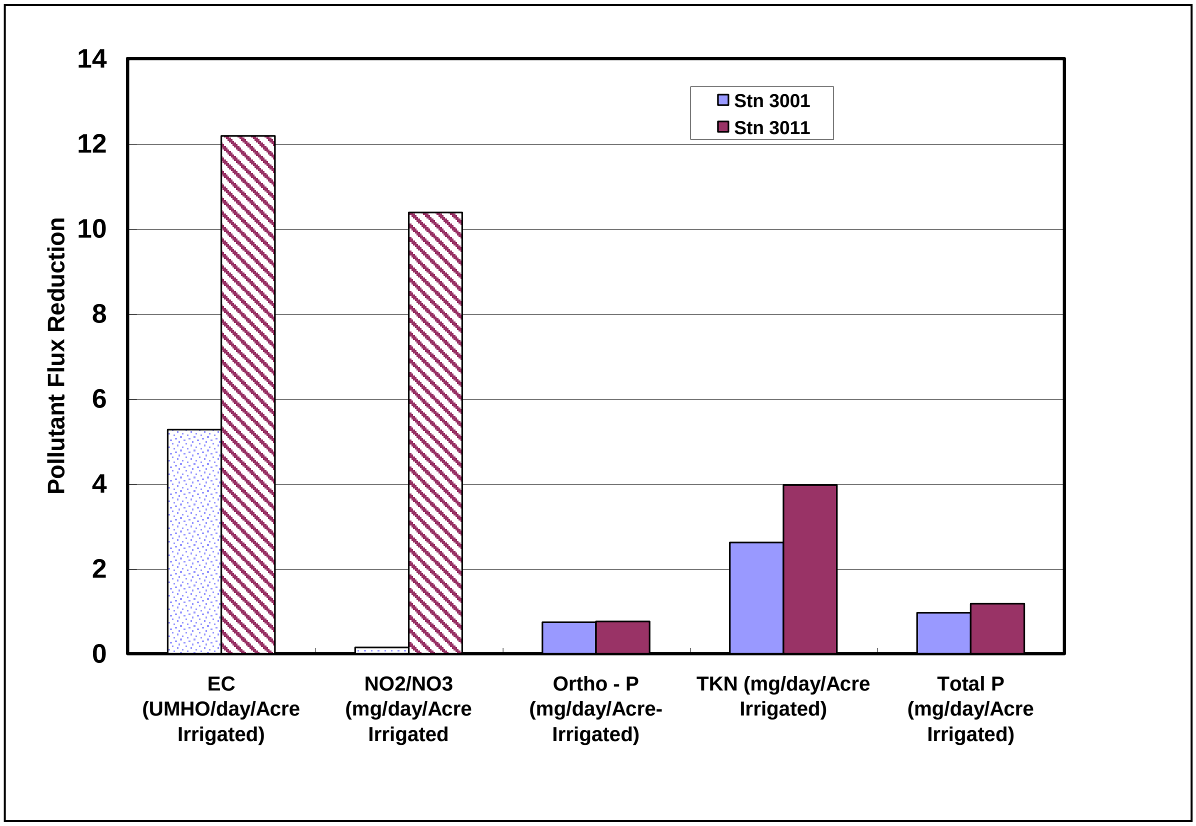

Figure 19: % Reduction in Mass Loading for Various Water Quality Parameters in Control and Retrofit Areas between Pre- and Post-Intervention Periods. (The dotted/stashed bars mean the concentrations are statistically different)

Section 8: Summary

In summary, the data indicated that the nitrate/nitrite concentrations in the Retrofit Area were higher than that of the Control Area, before as well as after the installation of Smart Timers. Also, the water quality data for some parameters (EC and nitrate/nitrite) for the Control and Retrofit Areas belonged to different distributions. Reasons for these differences are not currently known. The distribution for the other water quality parameters did not differ substantially between the Control and Retrofit Areas. Concentrations of some parameters (EC, TKN) decreased for the Control Area during the post-intervention period. However, no significant decrease in concentrations was observed for the Retrofit Area after the installation of Smart Timers. The runoff flow rates for both the Control and Retrofit Areas decreased during the post-intervention period. However, the flow rate reduction in the Retrofit Station was significantly (approximately three times) than that in the Control Area. This suggested that installation of Smart Timers significantly lowered the runoff flow in the retrofit area. Mass Flux for some parameters (EC in Control Station; EC, Nitrate/Nitrite and TKN in the Retrofit Area) also decreased during the post-intervention period. However, mass flux reduction in the retrofit area (EC, nitrate/nitrite) was significantly (approximately an order of magnitude) larger than that in the control area. Therefore, we can conclude that the larger reduction in mass flux in the Retrofit Area is predominantly caused by the reduction in the runoff flow rate caused by the installation of Smart Timers.

Appendix A: Time Series Plots

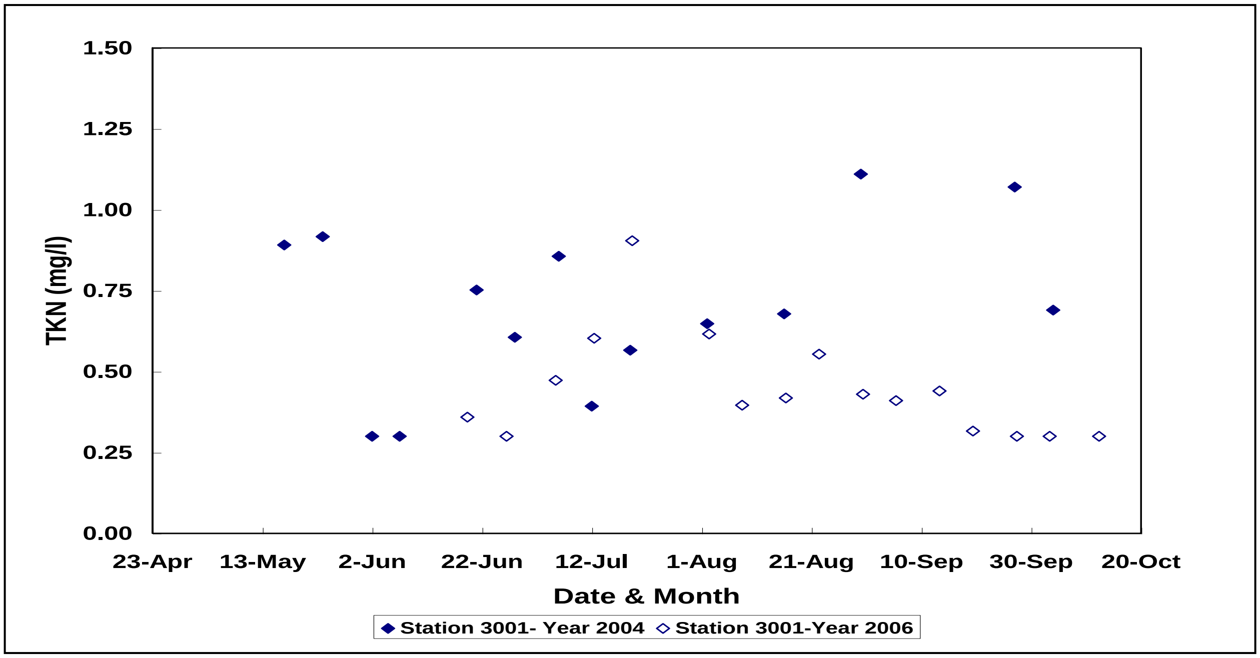

Figure A1. Time Series Plot for TKN in Control Station (#3001) during pre- and post-intervention periods

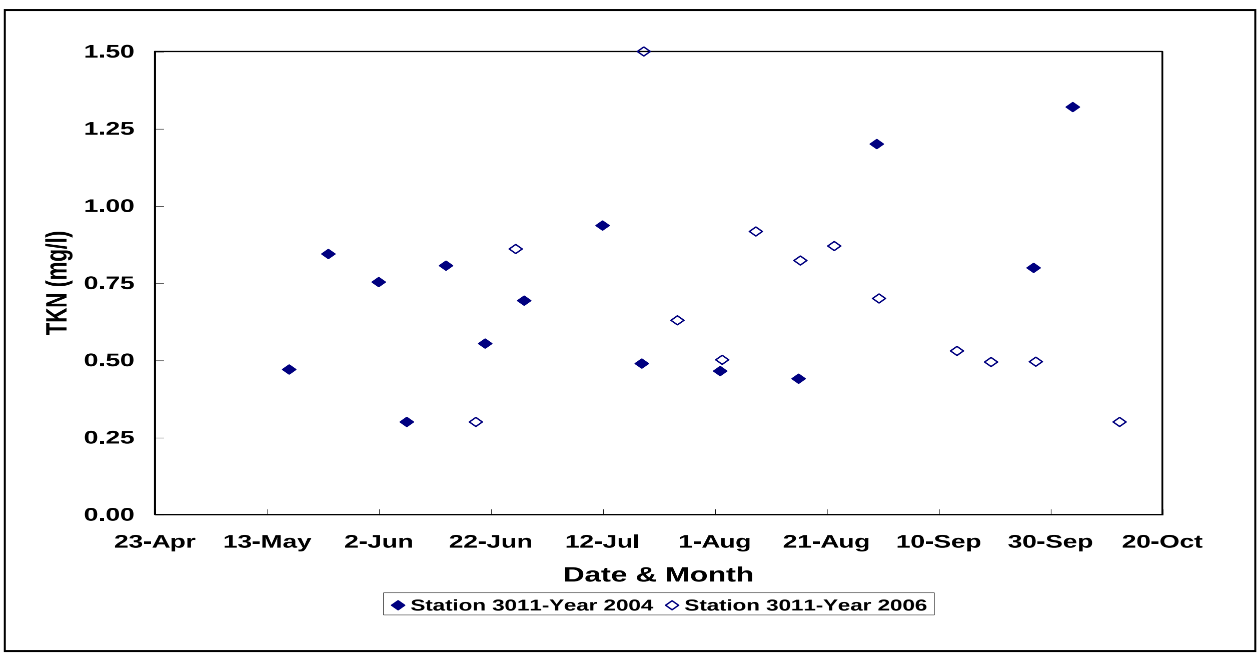

Figure A2. Time Series Plot for TKN in Retrofit Station (#3011) during pre- and post-intervention periods

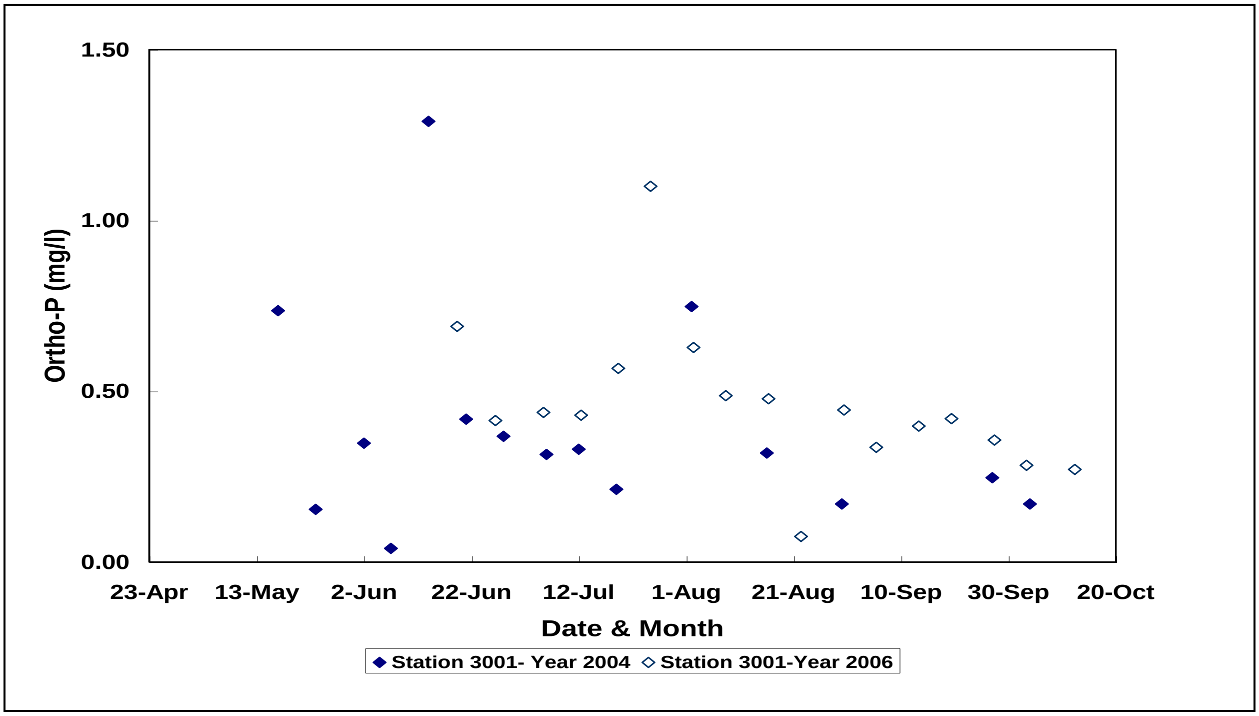

Figure A3. Time Series Plot for Ortho-P in Control Station (#3001) during pre- and post-intervention periods

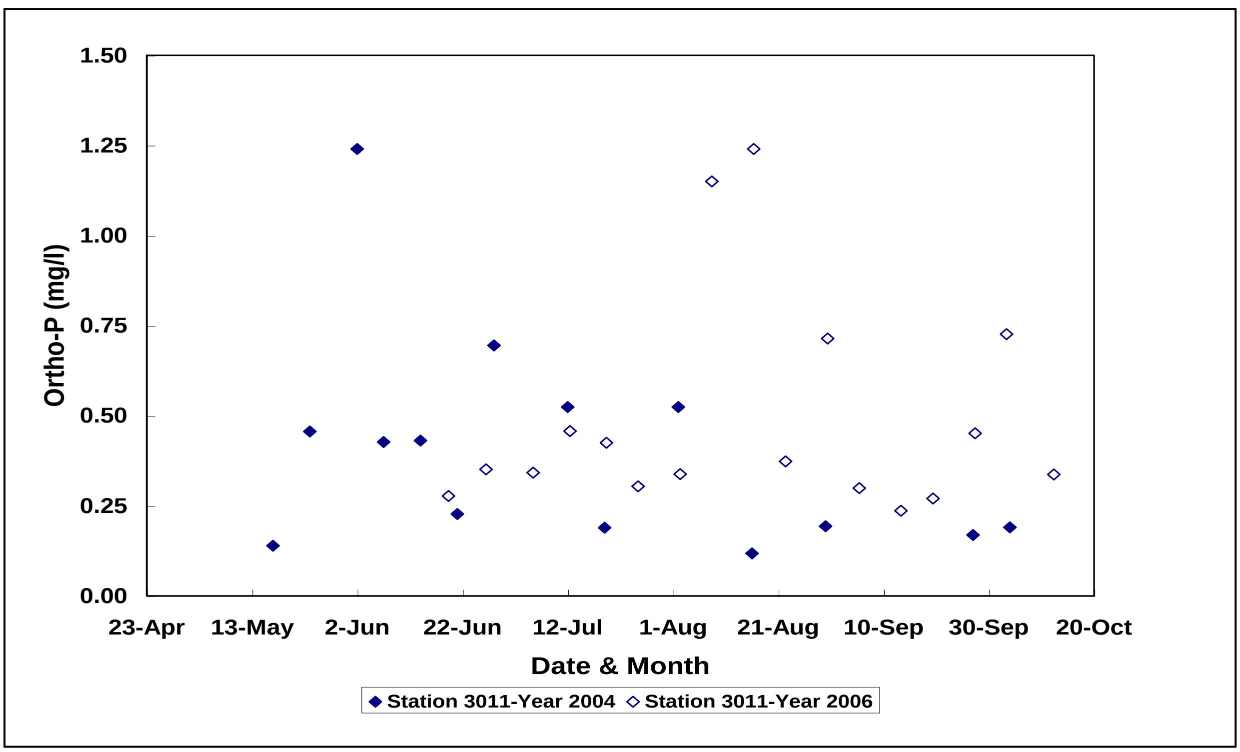

Figure A4. Time Series Plot for Ortho-P in Retrofit Station (#3011) during pre- and post-intervention periods

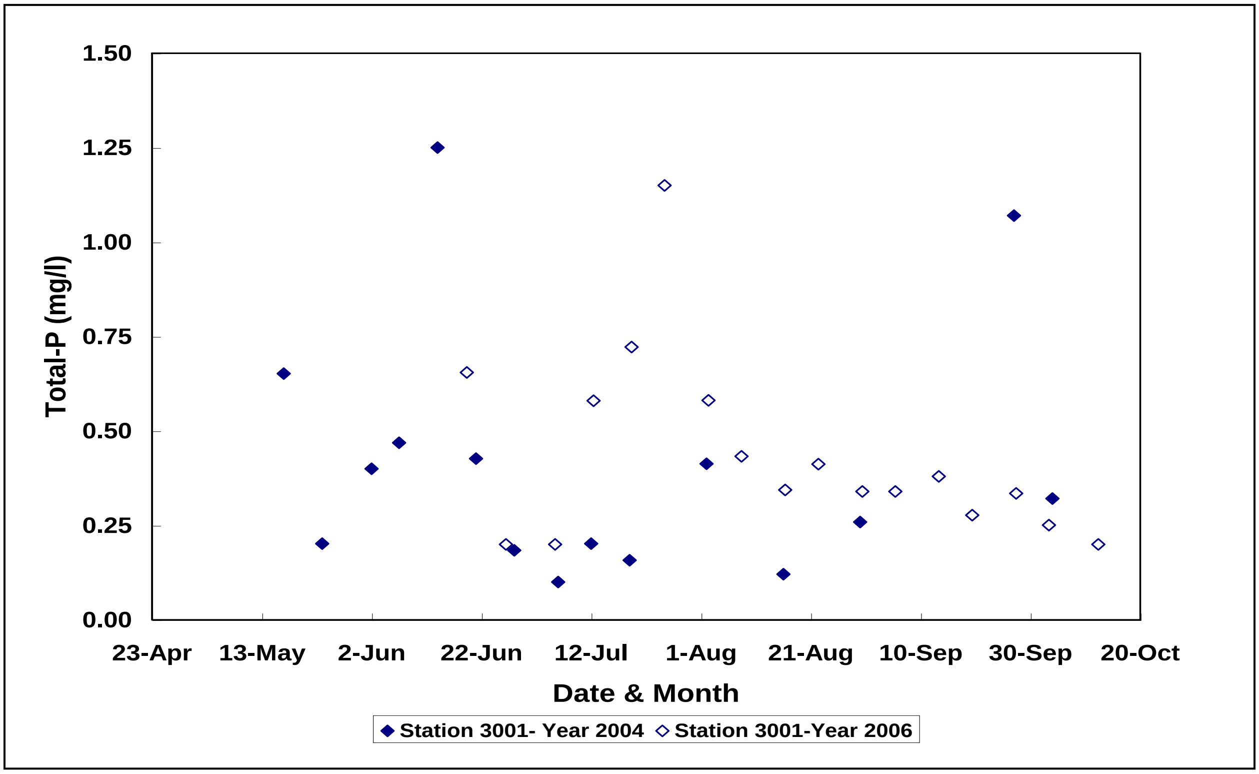

Figure A5. Time Series Plot for Total-P in Control Station (#3001) during pre- and post-intervention periods

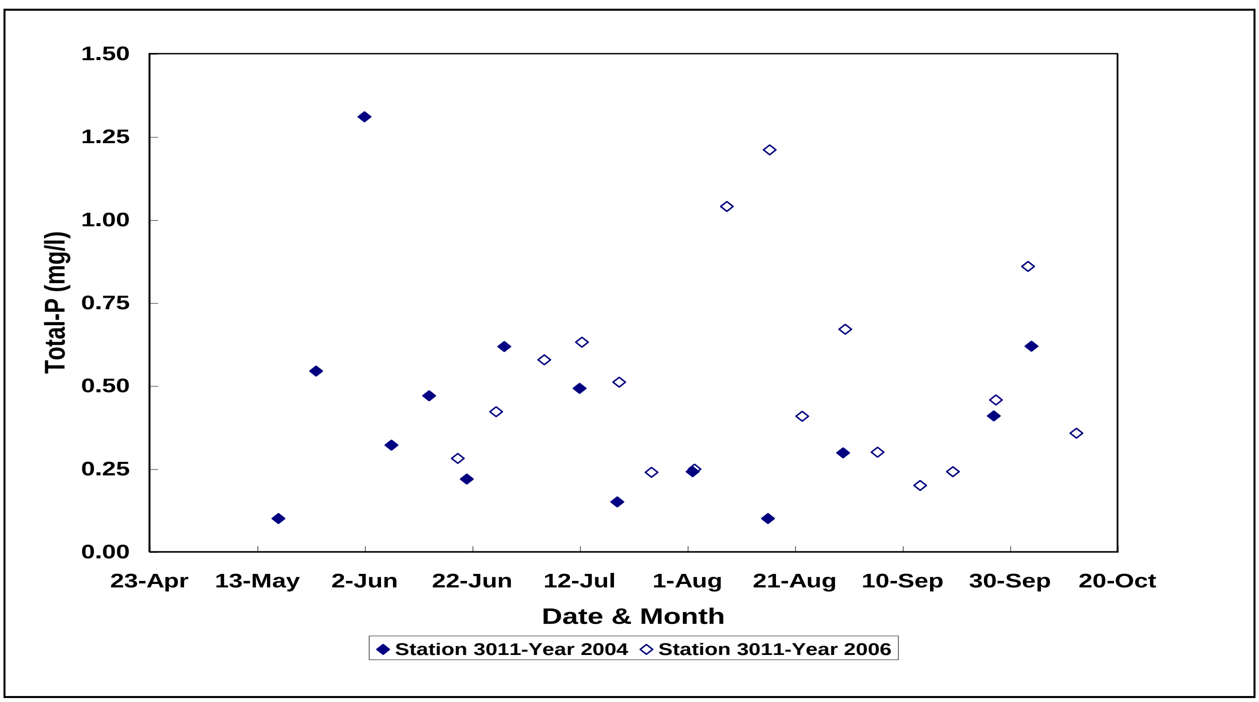

Figure A6. Time Series Plot for Total-P in Retrofit Station (#3011) during pre- and post-intervention periods

Appendix B: Cumulative Frequency and Box Plots

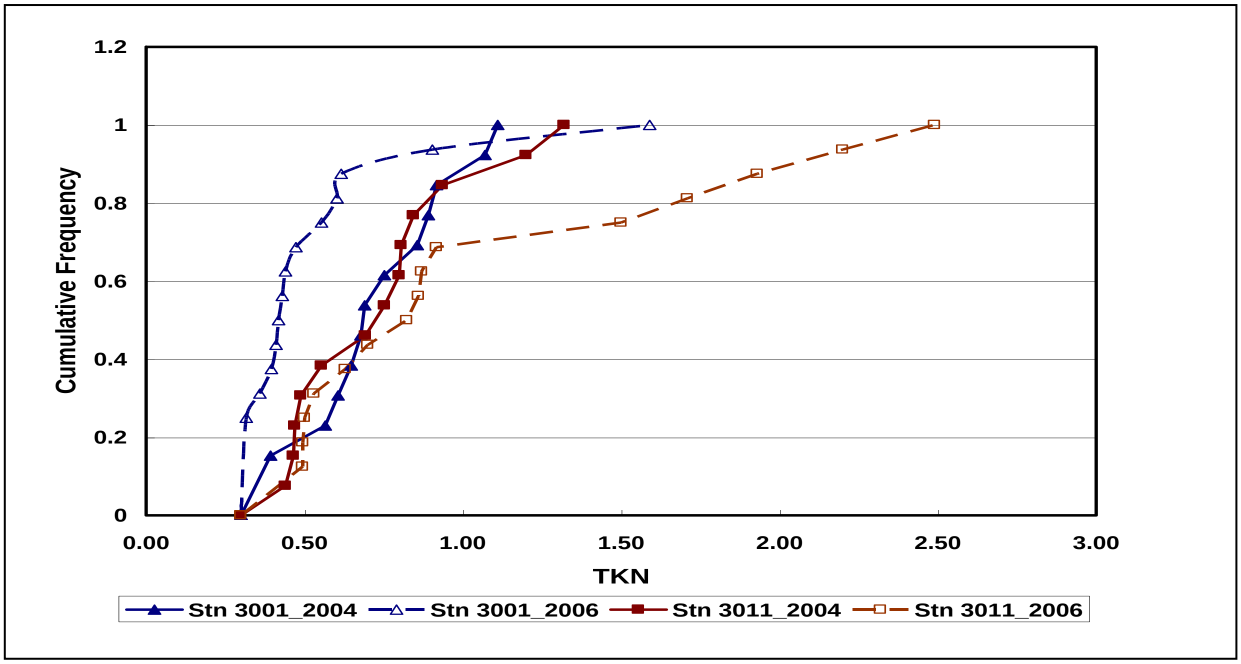

Figure B1. Cumulative Frequency Plot for TKN in Control and Retrofit Stations during pre- and post-intervention periods

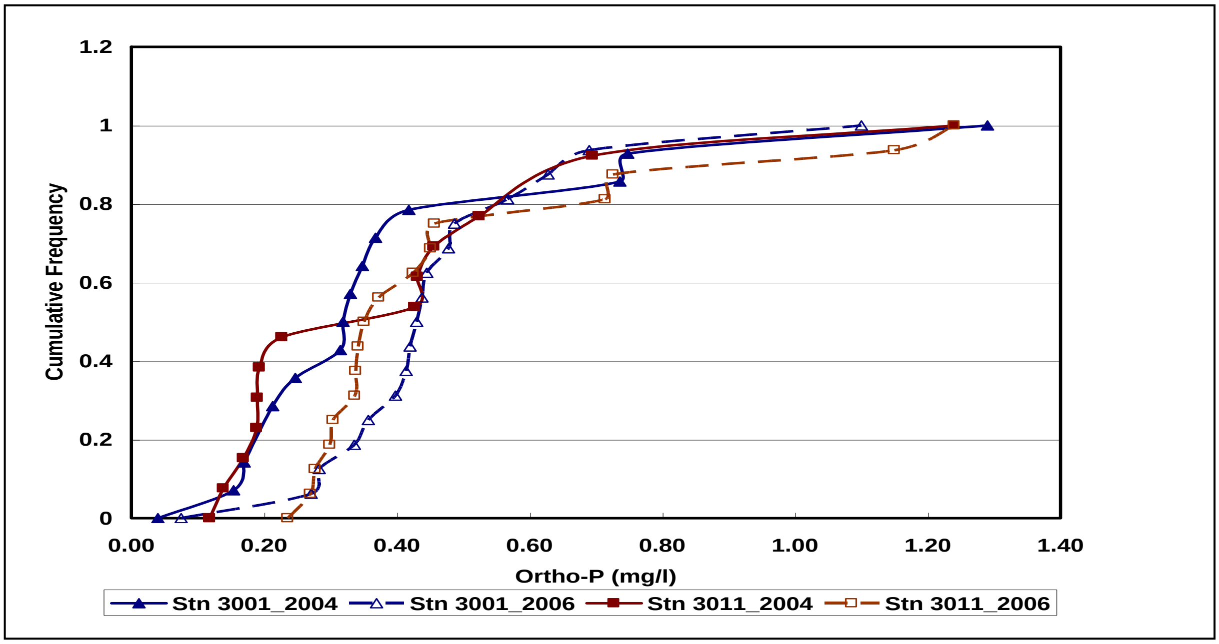

Figure B2. Cumulative Frequency Plot for Ortho-P in Control and Retrofit Stations during pre- and post-intervention periods

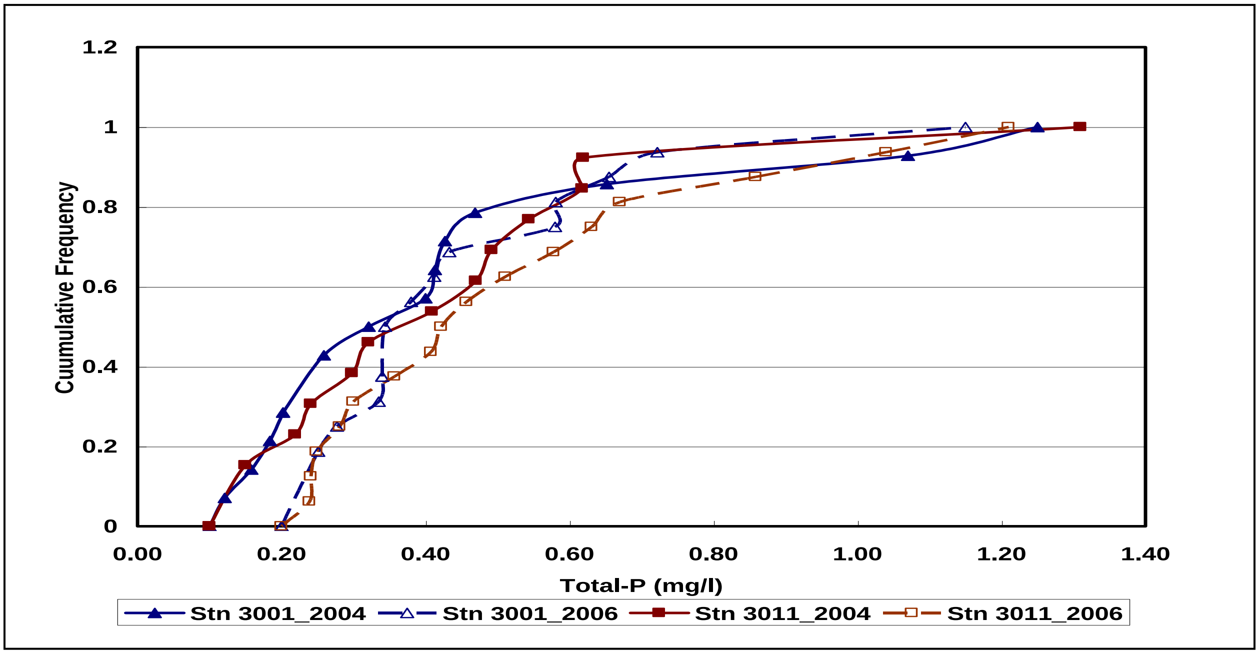

Figure B3. Cumulative Frequency Plot for Total-P in Control and Retrofit Stations during pre- and post-intervention periods

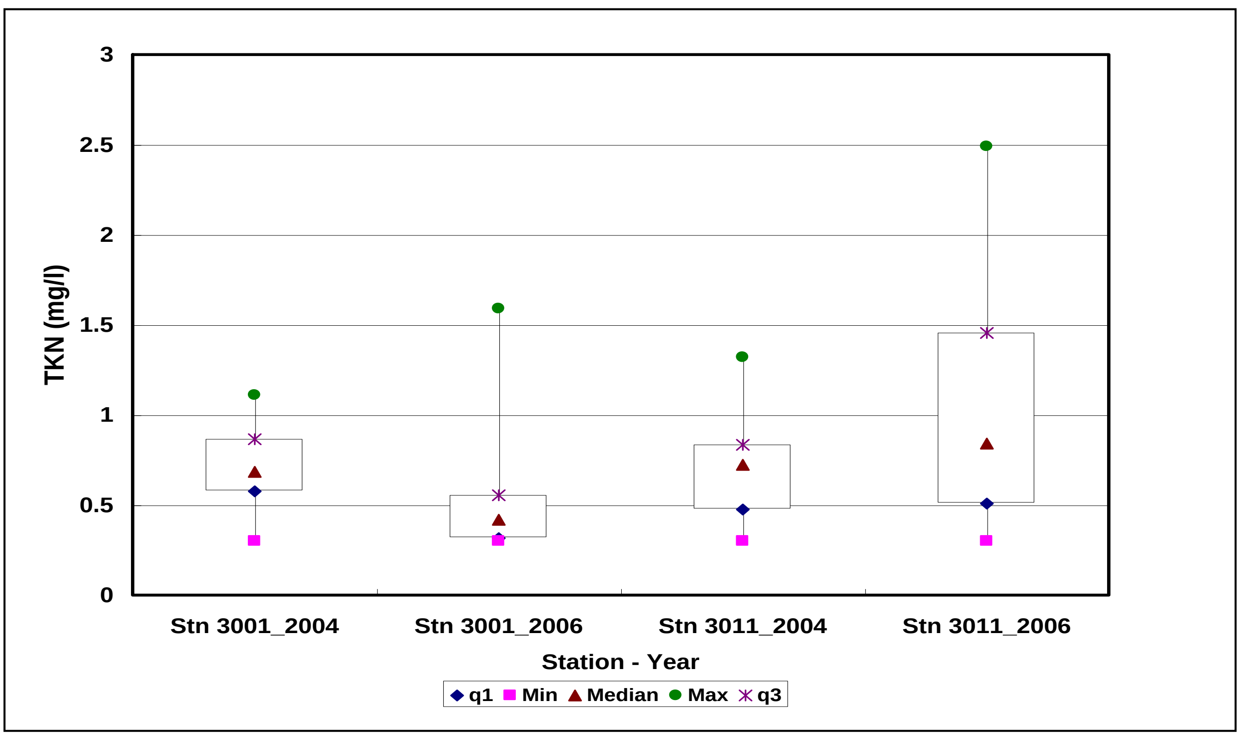

Figure B4. Box Plot for TKN in Control and Retrofit Stations during pre- and post-intervention periods

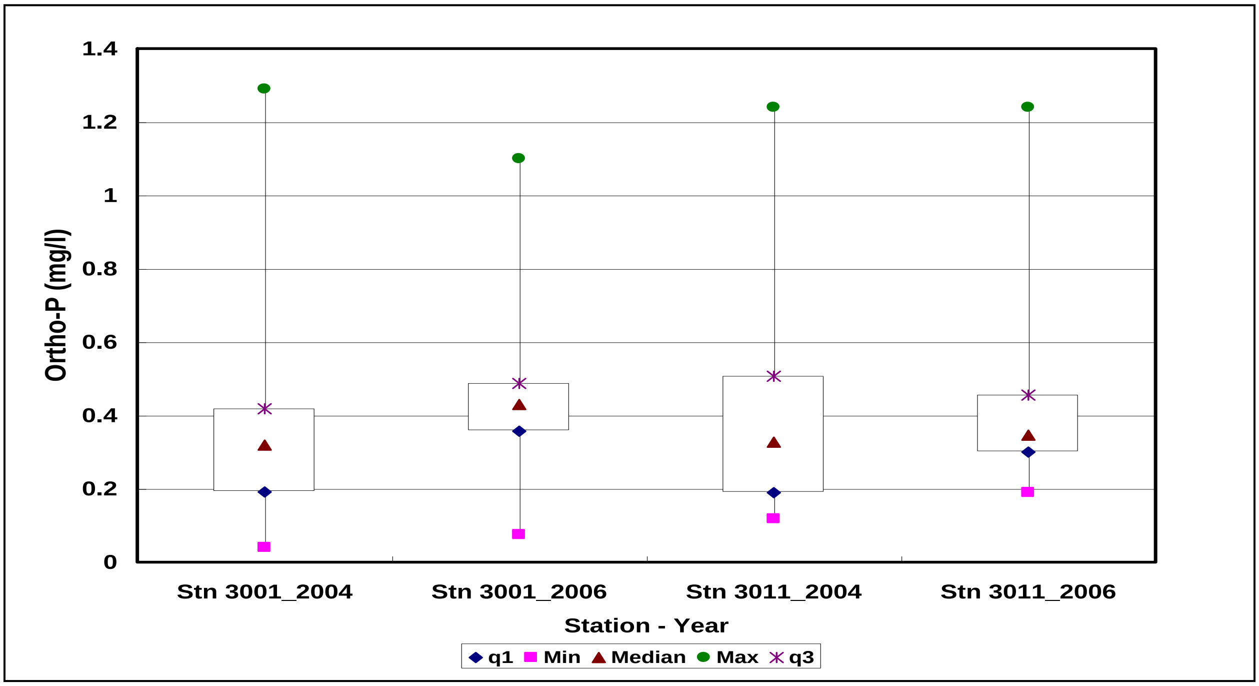

Figure B5. Box Plot for Ortho-P in Control and Retrofit Stations during pre- and post-intervention periods

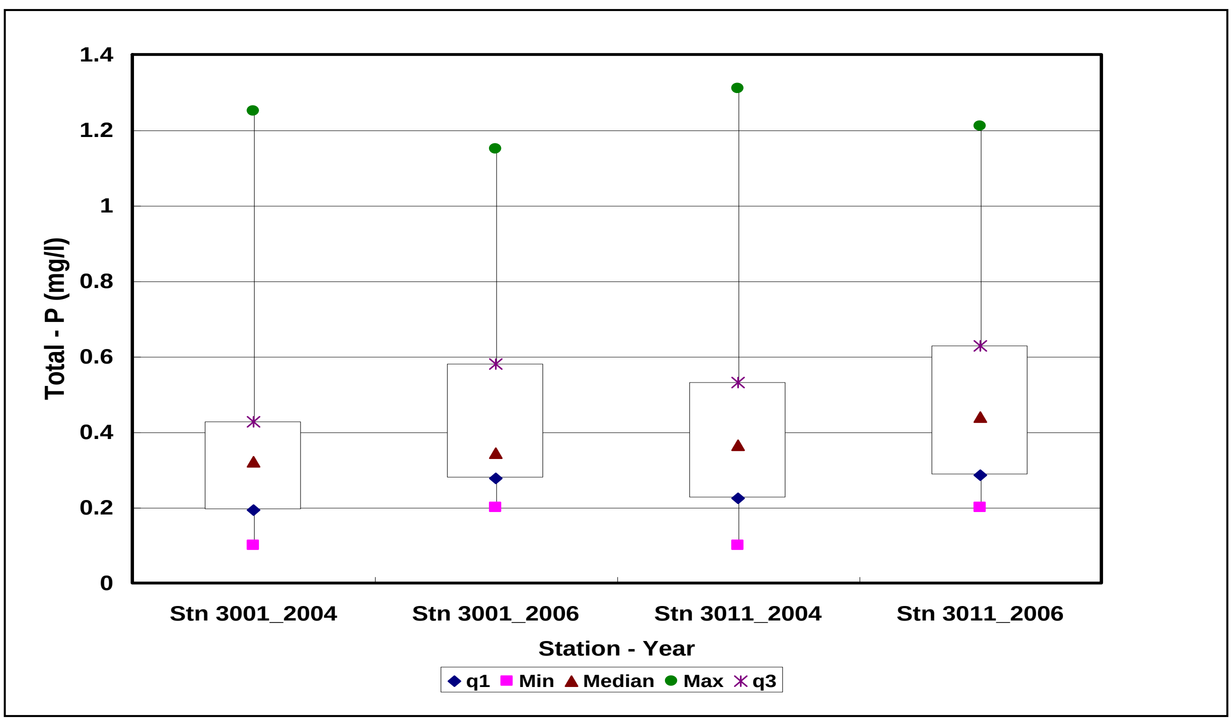

Figure B6. Box Plot for Total-P in Control and Retrofit Stations during pre- and post-intervention periods